

Design of an Electrostatic Lunar Dust Repeller for Mitigating Dust Deposition on Surfaces

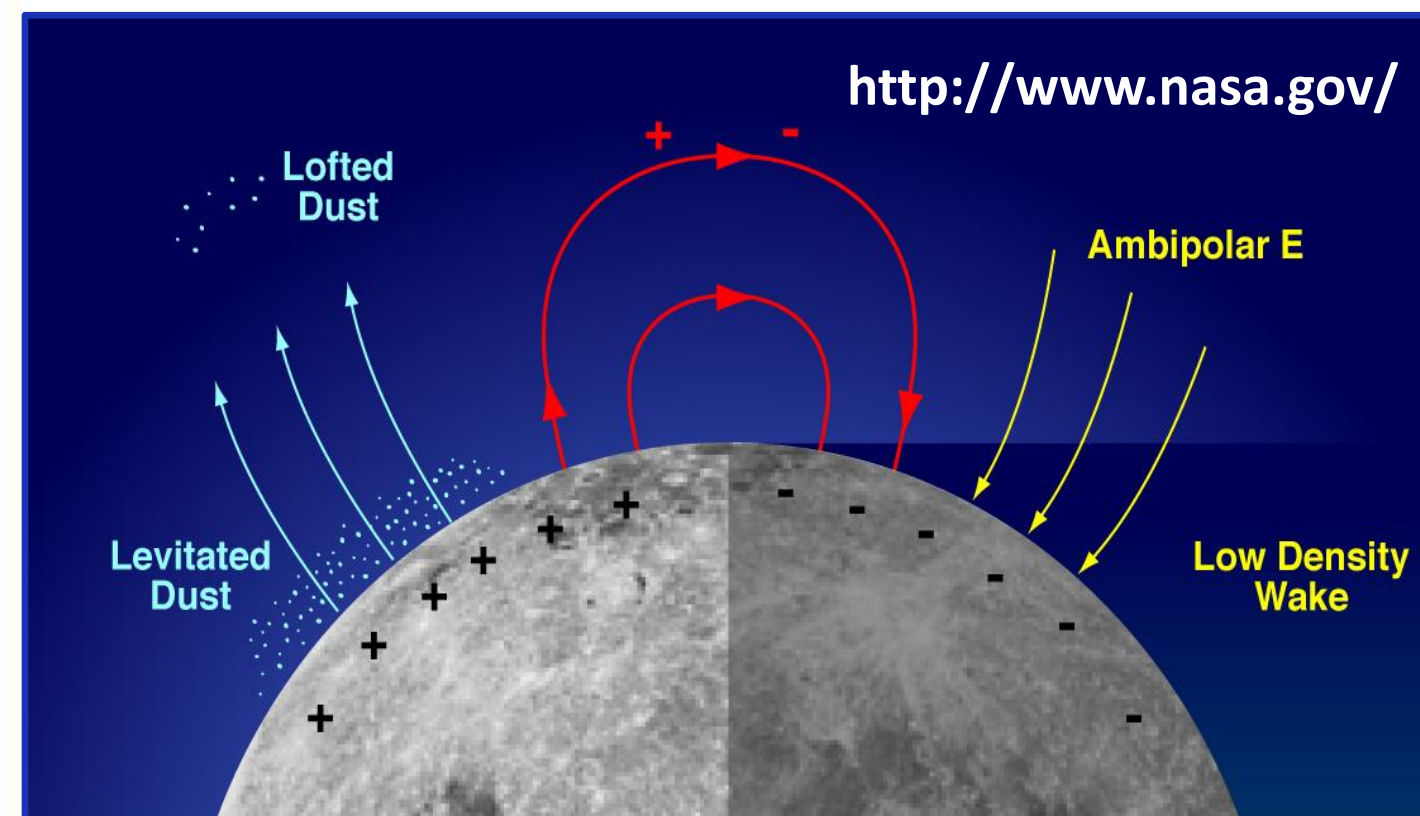
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INTRODUCTION

Accumulation of solar-based charges on lunar grains and consecutive levitation of the fine like-charged particles from the moon's surface was one of the biggest surprises of the Apollo era.



The Levitated particles fall down eventually and deposit on exposed sensitive surfaces causing:

- 1) Deterioration of solar panel performance
- 2) Degradation of thermal radiators
- 3) Obscuration of optical surfaces
- 4) False instrumentation of the measuring devices

An electrostatic lunar dust repeller (ELDR) was developed to mitigate the dust deposition. The ELDR consists of a set of thin rod-shaped electrodes oriented perpendicularly to the protected surface. All electrodes carry the same electrical charge polarity as they are all connected to the same terminal of the power supply with the same charge polarity as the incoming particles. The other terminal is connected to a grounded wire surrounding the entire protected area on top, to conduct the electrostatic field streamlines upward and away from the protected surface.

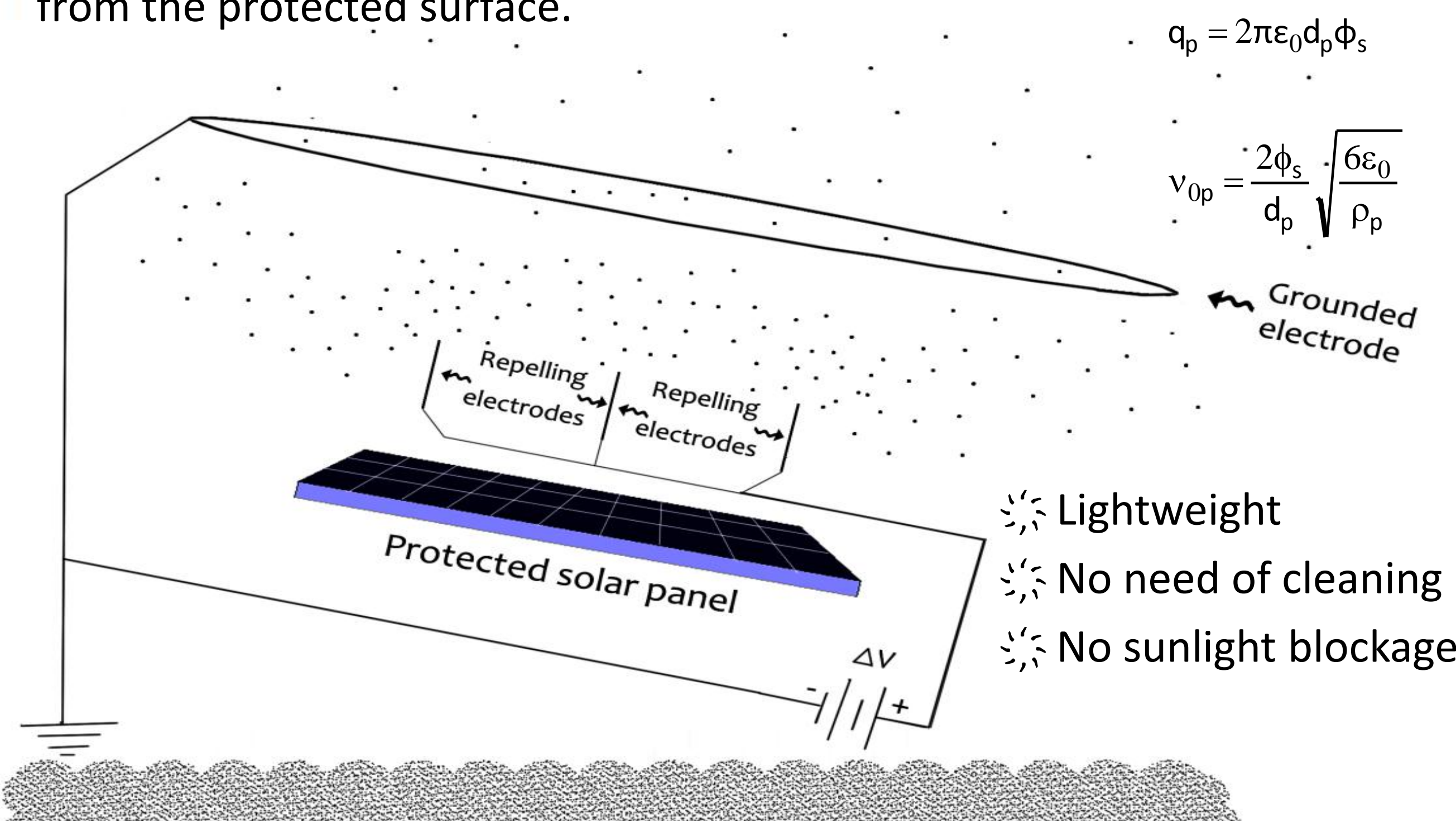


Fig. 1. Schematic of the ELDR configuration to protect an exposed surface

$$Z_{\max} = \frac{12\varepsilon_s \phi_s^2}{\rho_p g_l d_p^2} \quad \text{for } Z_{\max} = 50 \text{ cm} \Rightarrow d_p = 20 \mu\text{m}$$

METHOD

1) Single-Electrode ELDR

Charge Distribution on Electrode

Solving the integral form of Poisson's equation with developed MATLAB code.

$$\Delta V = \int \frac{\rho_s}{4\pi\epsilon_0 r} ds$$

q_p = Particle charge
 Φ_s = Surface potential of the particle
 v_{0p} = Initial particle velocity
 Z_{\max} = Maximum levitation height
 ϵ_0 = Permittivity of the space
 g_l = Gravitational acceleration
 d_p = Particle diameter
 ρ_p = Particle density
 ΔV = Applied voltage on the electrode
 ρ_s = Surface charge density on the electrode
 r = Position vector between each point of space with respect to the origin

Discrete Element Method (DEM)

DEM is a Lagrangian-based model to track particle trajectories.

EDEM 2.4.4 developed by DEM Solutions, Inc. with dedicated module for electrostatic calculations was implemented.

Initial arrangement of uniformly distributed particles inside a particle factory with particle positions updates at each time-step based on Newton's second law and kinematic equations of the motion.

Sensitivity analyses on: applied voltage, particle number & electrode length

Removal efficiency: the percentage of the particles repelled away from the protected surface before passing the electrode length.

A Dell Precision T5500 Workstation with 8 Intel[®] Xenon[®] CPU E5620 cores with a processing speed of 2.4GHz, and 8GB DDR3 of RAM was used (8 hr/run for the single-electrode & 4 day/run for the ensemble-electrode ELDR).

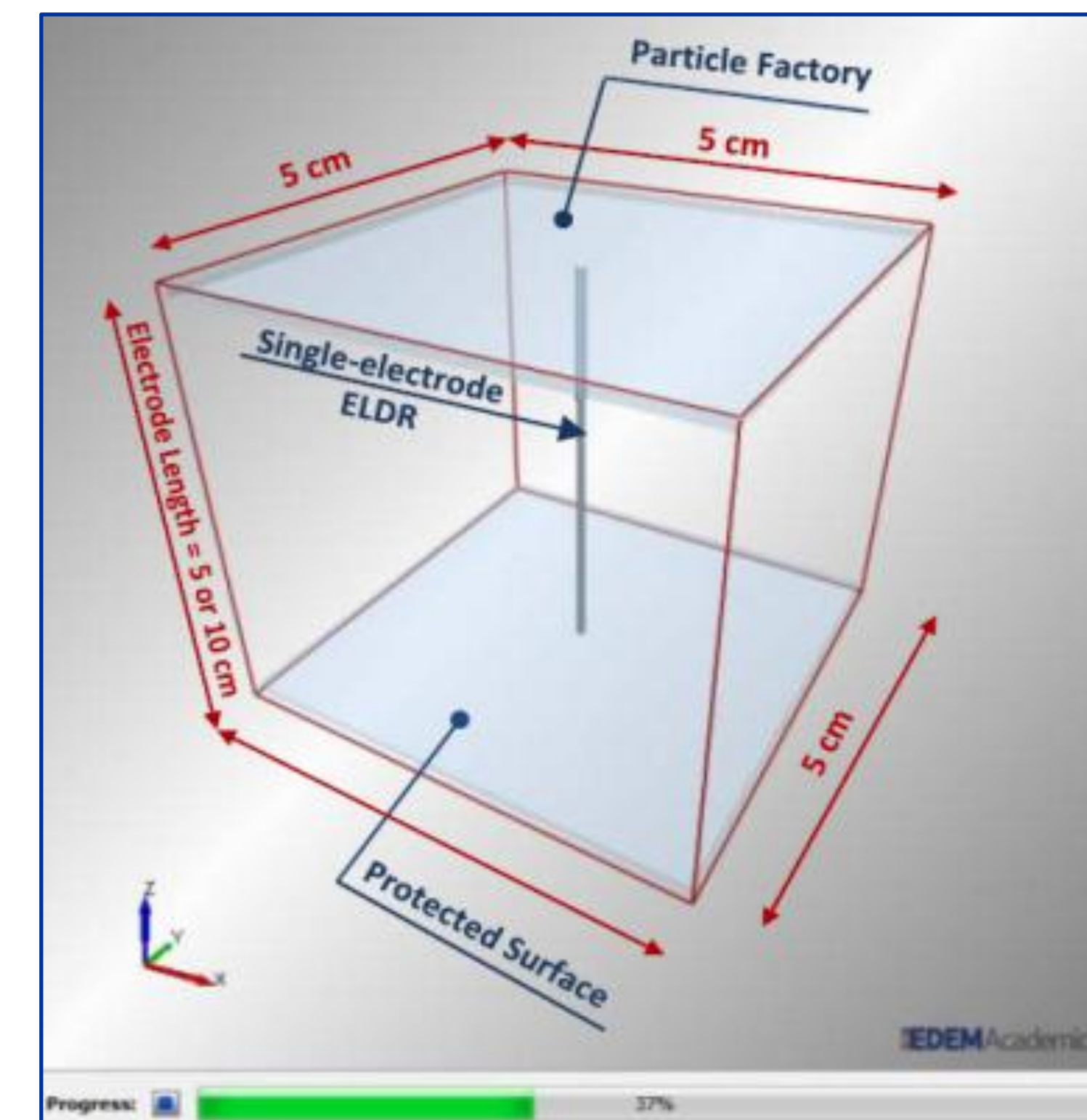


Fig. 2. DEM model for the Single-electrode ELDR

Analysis of Particle Trajectories

Visual Basic for Application (VBA) code was developed to process the obtained output logs and to determine the ELDR removal efficiency.

2) Ensemble-Electrode ELDR

The goal is applying an appropriate arrangement of a certain number of electrodes to protect a 30 cm x 30 cm surface at even lower electric power.

Recognition of the Optimum Electrode Arrangement

Finite element analysis (FEA) was conducted using COMSOL 4.2 to obtain electric potential distribution and electric field streamlines solving:

$$\Delta V_{ij} = \sum_{i=1}^n \sum_{j=1}^m \frac{\rho_{ij} \Delta l}{4\pi\epsilon_0 |\vec{r} - \vec{r}_{ij}|^2}$$

$$\vec{E}_{xyz} = \sum_{i=1}^n \sum_{j=1}^m \frac{\rho_{ij} \Delta l (\vec{r} - \vec{r}_{ij})}{4\pi\epsilon_0 |\vec{r} - \vec{r}_{ij}|^3}$$

n = Number of electrodes
 m = Number of discretized segments on each electrode
 r = Position vector of observation point with respect to the origin
 r_{ij} = Position vector of the j^{th} segment with respect to the i^{th} electrode
 ρ_{ij} = Charge density of the j^{th} segment on the i^{th} electrode
 L = Electrode length
 D = Electrode diameter

RESULTS

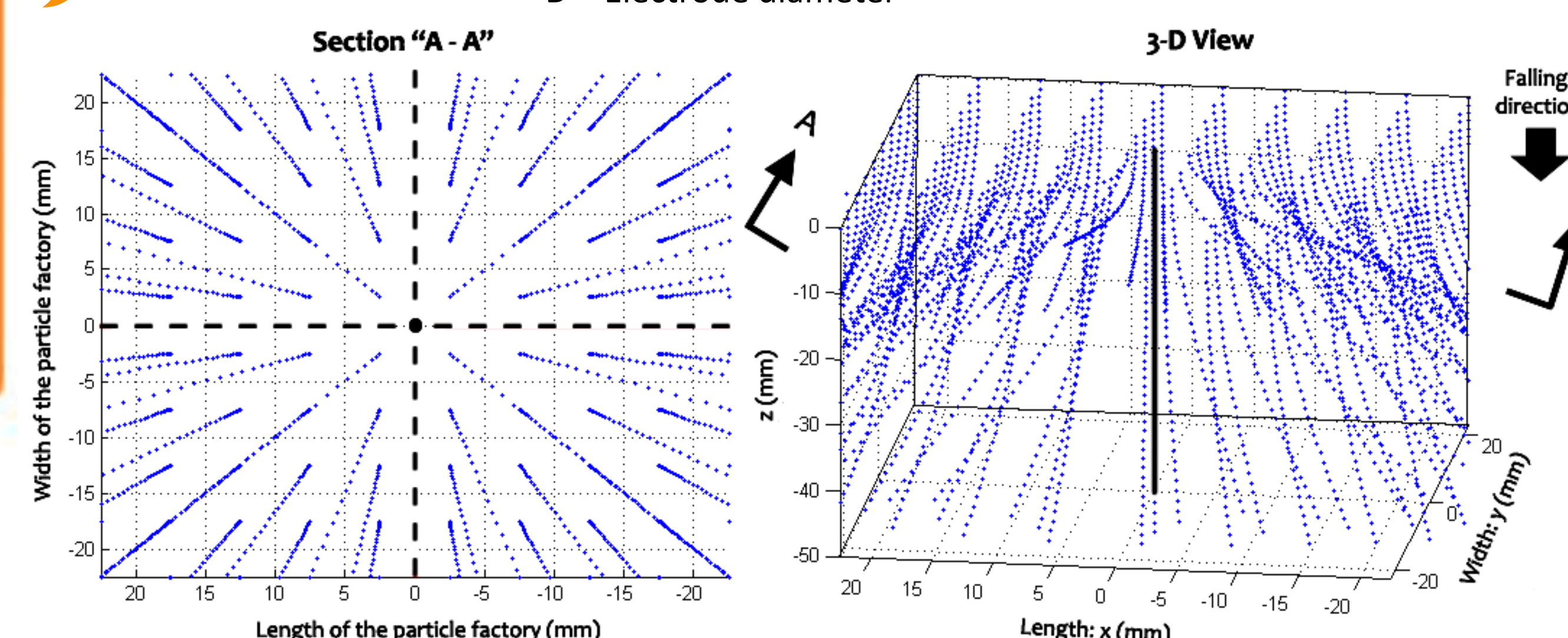


Fig. 3. Particle trajectories of 100 falling particles for the single-electrode ELDR (L = 5 cm & D = 1 mm) at ΔV = 4 kV

Fig. 4. Sensitivity analyses on the applied voltage, particle # concentration & electrode length to protect the 5 cm x 5 cm surface

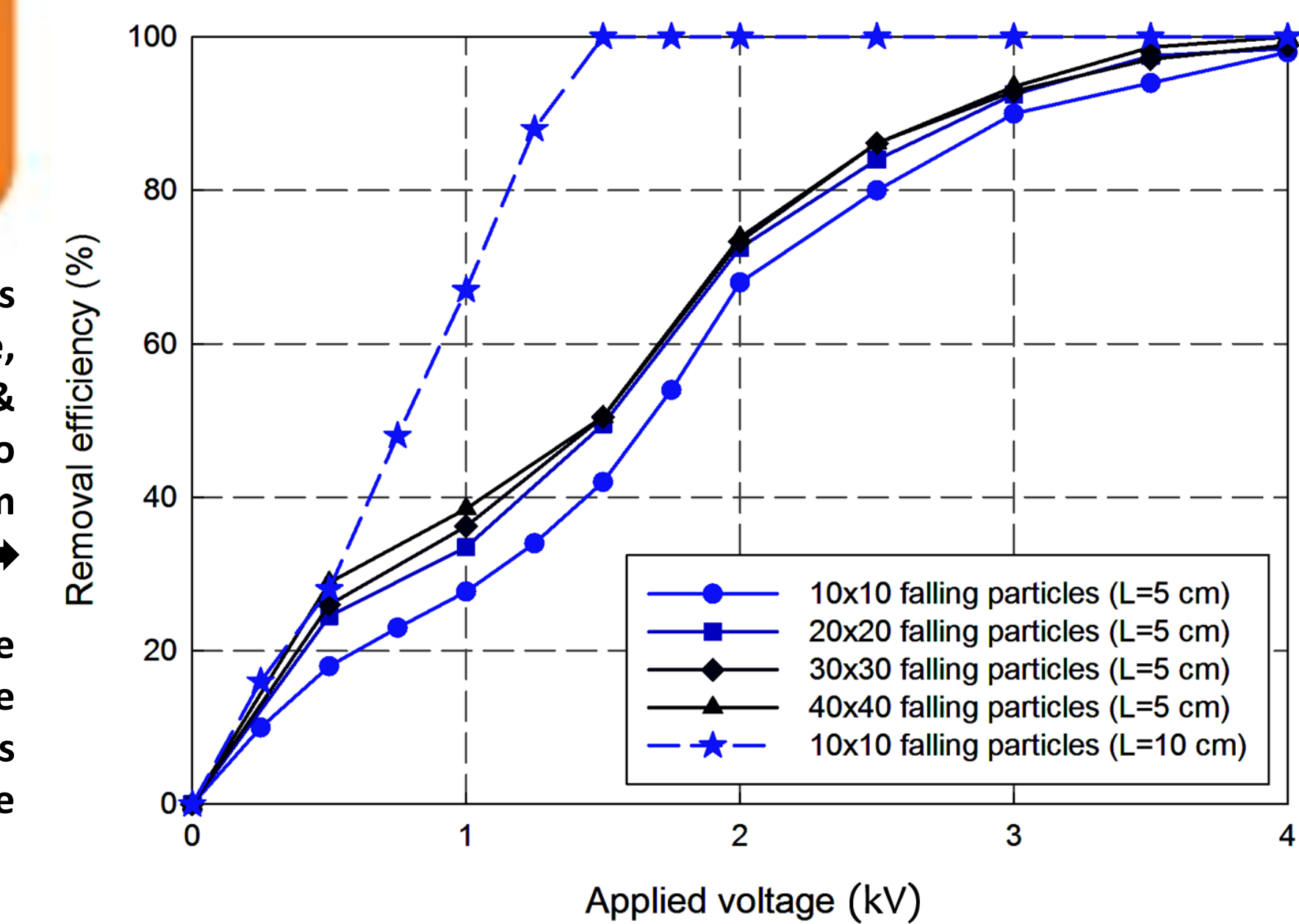


Fig. 5. Plan view of some examined electrode arrangements of this study to show dead zone areas

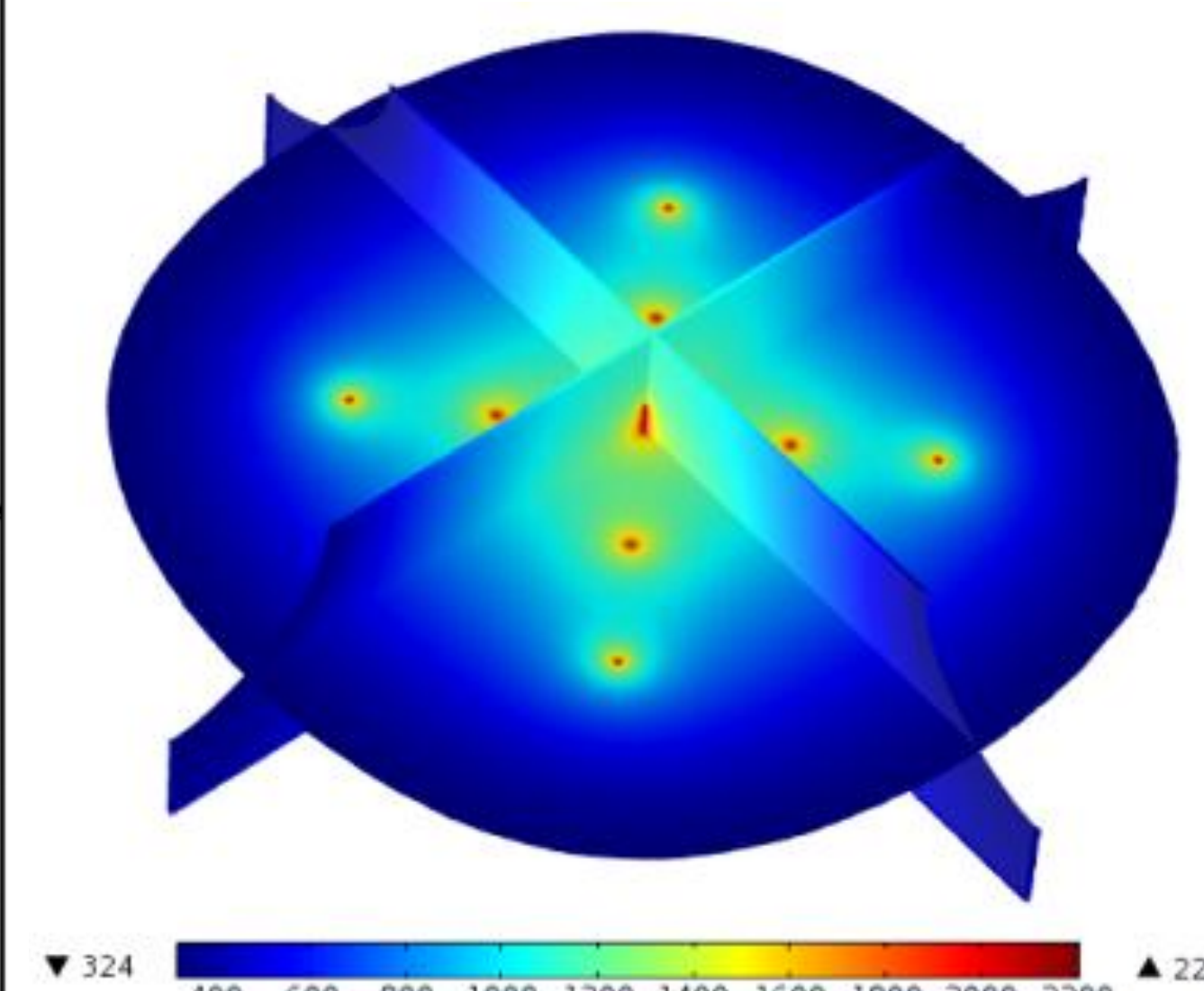
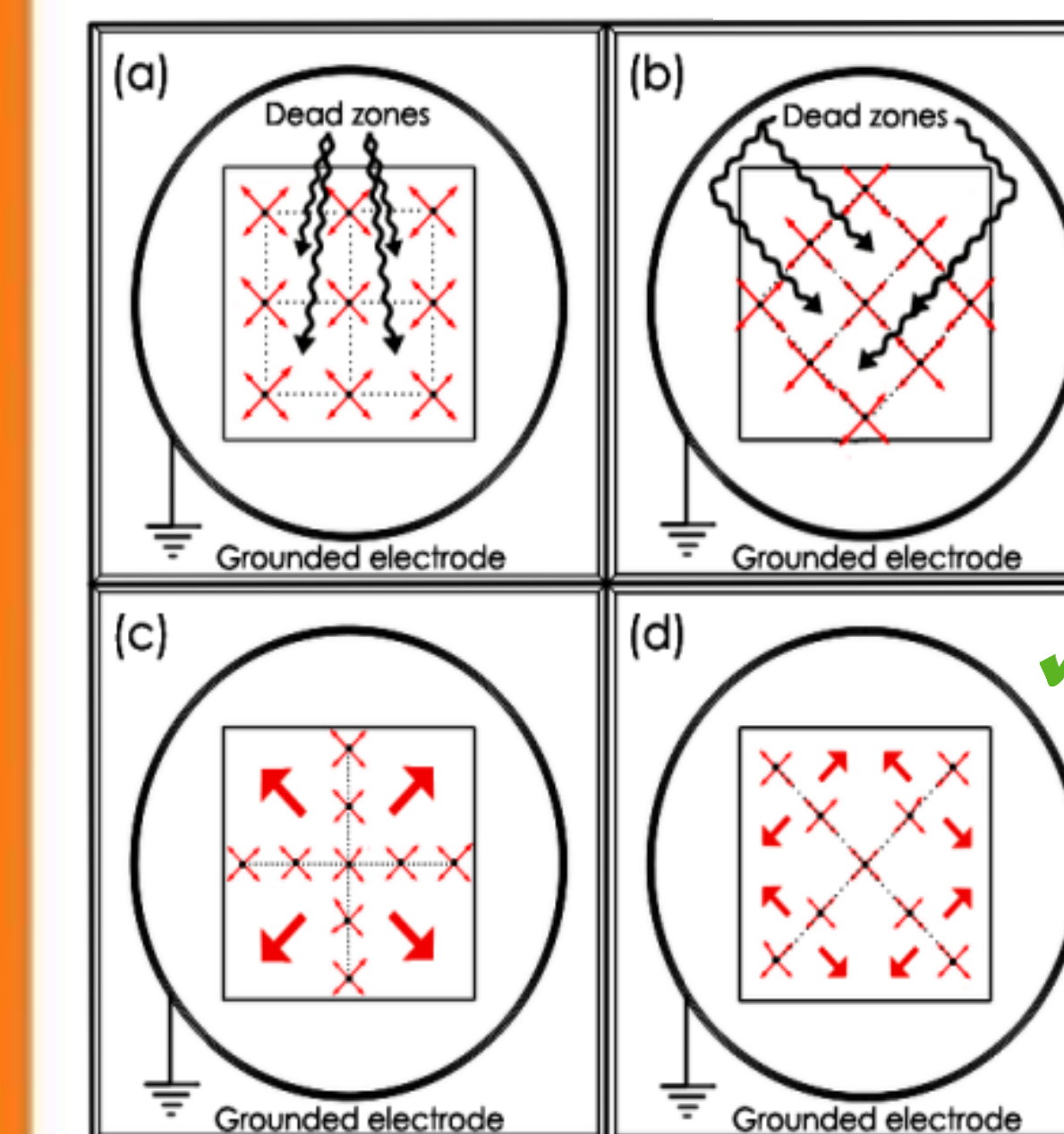


Fig. 6. 3-D Electric potential distribution at ΔV = 2.2 kV

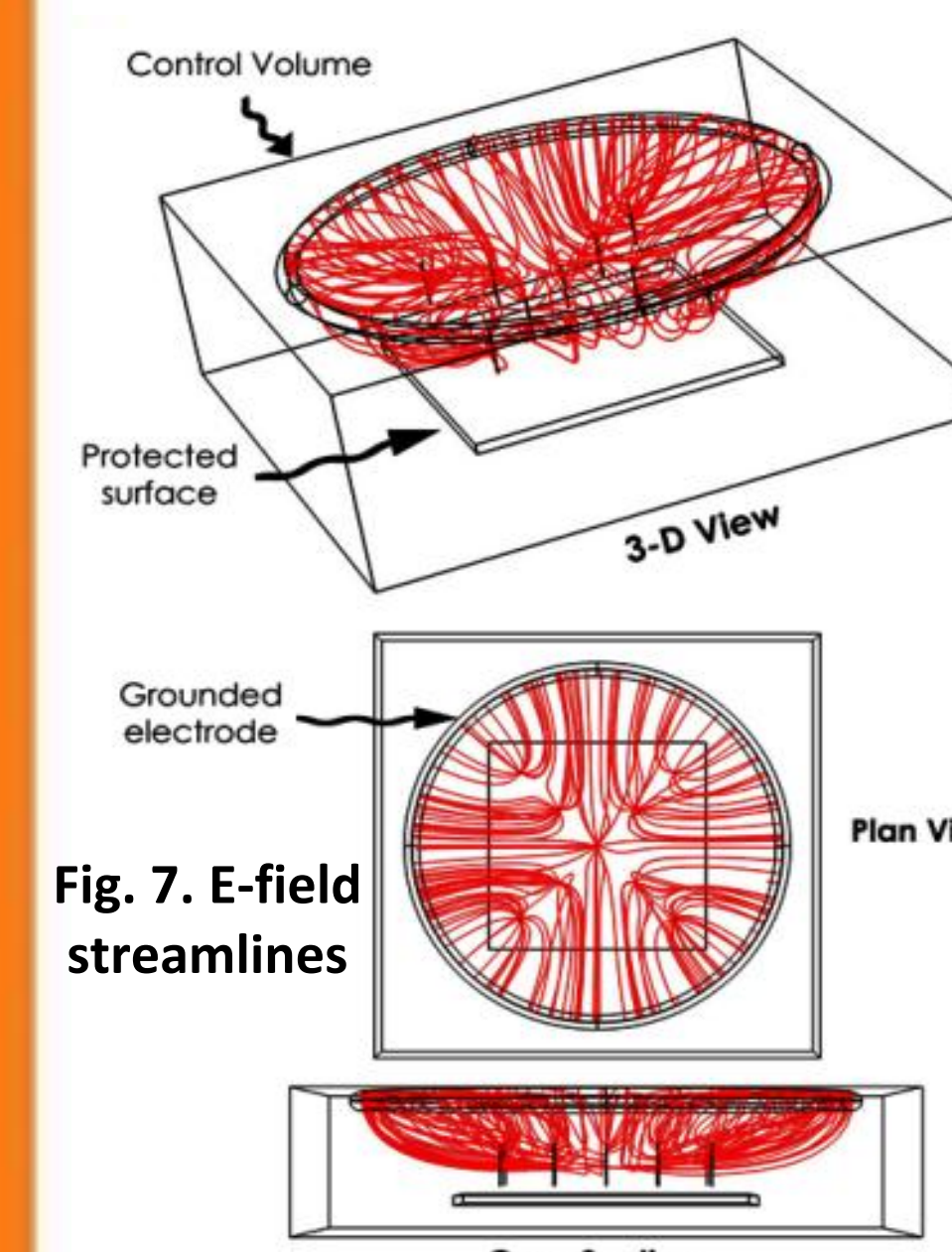


Fig. 7. E-field streamlines

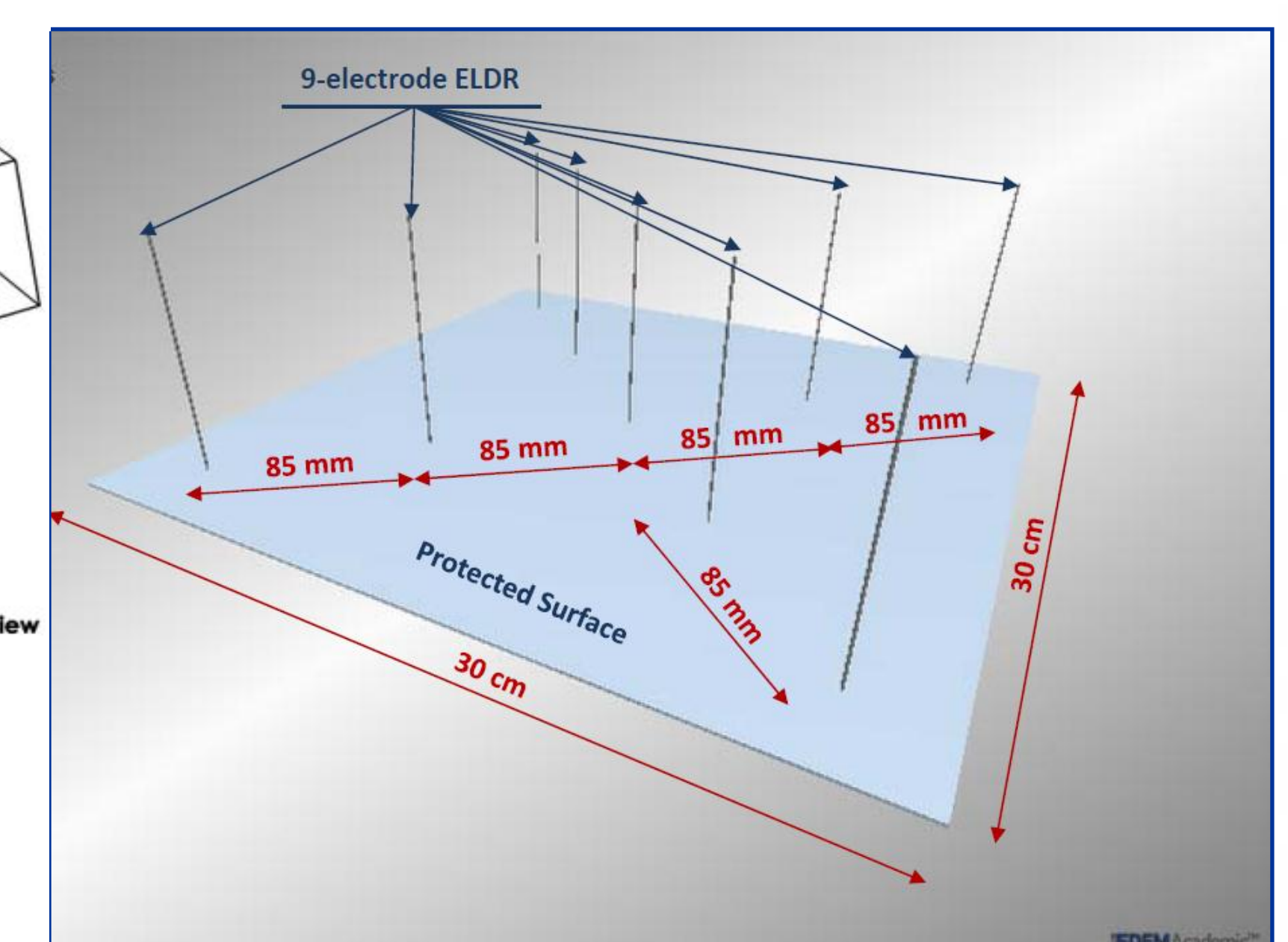


Fig. 8. Geometry of the DEM model of the Ensemble-electrode ELDR

CONCLUSIONS

- Single-electrode ELDR needed 4 kV for L=5 cm and 1.5 kV for L=10 cm to achieve 100% removal efficiency over the 5 cm x 5 cm surface.
- Increase in number concentration of the lunar dust was beneficial.
- Cross-shaped ensemble-electrode ELDR was the most effective electrode arrangement as it has no dead zone areas and averagely requires shortest lateral distance to shift particles away.
- The removal efficiencies of the studied 9-electrode ensemble ELDR at 2.2 kV for L=5 cm was 92%; and at 1.4 kV for L=10 cm was 100%.

ACKNOWLEDGEMENTS

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